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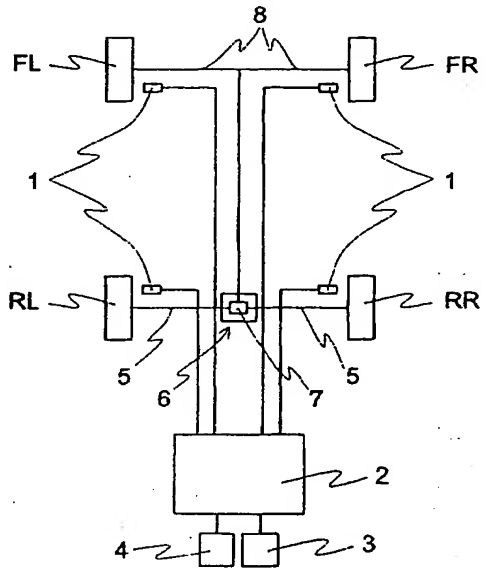
## (54) Apparatus and method for alarming decrease in tyre air pressure

(57) An apparatus for alarming decrease in tyre air-pressure on the basis of a rotational information obtained by tyres attached to a four-wheeled vehicle, comprising rotational information detecting means; memory means for storing the rotational information; calculation processing means for calculating a reciprocal number of a turning radius and calculating a judged value, first judging means for comparing the judged value with a reference value at every region of the turning radius; and second judging means for cancelling a judgement of decrease of internal pressure when a difference between the judged values in the right and left turning regions is different from a difference between reference judged values in the right and left turning regions which are obtained at a time of initialising run.

FIG. 1




EP 1 145 875 A2

## Description

**[0001]** The present invention relates to an apparatus and method for alarming decrease in tyre air-pressure. In particular, the present invention relates to an apparatus and method for alarming decrease in tyre air-pressure which can suitably judge decrease in internal pressure of a tyre on a vehicle having a limited slip differential device (LSD) thereon so as to securely prevent an erroneous alarm from being issued.

**[0002]** Conventionally, it is known that on deflation the dynamic load radius of a tyre becomes smaller and the rotational speed becomes faster in comparison with a tyre having a normal pneumatic pressure. For example, in Japanese Unexamined Patent Publication No 149119/1995, there has been proposed a method of detecting decrease in internal pressure on the basis of relative different of number of revolutions of the tyre. Further, since the rotational speed of the tyre is influenced by turning of the vehicle, speed, its acceleration and deceleration load, and the like, various devices have been tried to try to remove influences from these factors.

**[0003]** However, in order to improve running performance such as cornering performance, there are vehicles in which a limited slip differential device is used in the differential gear of the drive axle. The limited slip differential device is so arranged that differential operation is limited until the differential torque exceeds a pre-set value and until then the right and left driving wheels are rotated at the same speed. Accordingly, decrease in pneumatic pressure is not reflected in the number of revolutions. and so it is impossible to detect the pressure decrease by a relative comparison of the number of revolutions.

**[0004]** As shown in Figure 8, judged values (DEL values) are collected on a portion having a relation of horizontal axis = 0, that is, a vertical axis (Y axis) while the differential operation is limited regardless of an existence of pressure decrease and a position, when a pressure of a tyre in a rear right tyre RR or a front left tyre FL is decreased and a pressure of a tyre in a rear left tyre RL or a front right tyre FR is decreased as shown in Figure 8 in which a reciprocal number 1/R of a turning radius R calculated from the driving shaft is set to a horizontal axis (X axis). Accordingly, the applicant of the present application has found that the pressure decrease can be easily judged by comparing the judged value in a horizontal portion a little apart from the vertical axis (refer to Japanese Unexamined Patent Publication No 123911/1999). Therefore, the arrangement is made such that when a difference A or B between the judged value at a time of pressure decrease and the DEL value of the normal pneumatic pressure is over a certain range, it is judged that the pneumatic pressure of the certain tyre is decreased, whereby an alarm is issued.

**[0005]** However, in a clutch plate type LSD or the like, there is the case where the limited slip differential torque is chanted with the passage of time. For example, in the case where the limited slip differential torque is decreased (DTD) or increased (DTU) as shown in Figure 9 in comparison with a time of setting the pneumatic pressure of the tyre to the normal pneumatic pressure and initialising a pneumatic pressure alarm apparatus (at a normal time), there is a risk that the DEL value is changed even when the pneumatic pressure of the tyre is normal, and an erroneous alarm is issued in case the difference DTD or DTU with respect to the DEL value of the normal pneumatic pressure DS becomes equal to or more than a certain range.

**[0006]** The present invention is made in view of the above circumstances, and an object thereof is to provide an apparatus and method for alarming decrease in tyre air-pressure which can suitably judge decrease in an internal pressure of a tyre in a vehicle mounting a limited slip differential device (LSD) thereon so as to securely prevent an erroneous alarm from being generated.

**[0007]** According to the present invention, there is provided an apparatus for alarming decrease in tyre air-pressure which alarms decrease of internal pressure of a tyre on the basis of rotational information for tyres on a four-wheeled vehicle comprising rotational information detecting means for detecting rotation information for each of the tyres; memory means for storing the rotational information of each of the tyres; calculation processing means for calculating a reciprocal number of a turning radius from the rotational information of the tyre attached to a driving shaft among the rotational information of the respective tyres and calculating a judged value from the rotational information of the respective tyres; first judging means for comparing the judged value with a reference value at every region of the turning radius on the basis of a relation between the reciprocal number of the turning radius and the judged value so as to judge decrease in internal pressure; and second judging means for cancelling a judgement of decrease of internal pressure when a difference between the judge value in the right turning region and the judged value in the left turning region is different from a difference between a reference judged value in the right turning region and a reference judged value in the left turning region which are obtained during an initialising run.

**[0008]** Further, in accordance with the present invention, there is provided a method for alarming decrease in tyre air-pressure which alarms decrease of internal pressure of a tyre on the basis of a rotational information obtained for tyres on a four-wheeled vehicle, comprising the steps of comparing a judged value with a reference value at every region of a turning radius so as to judge decrease in internal pressure on the basis of a relation between a reciprocal number of the turning radius calculated from the rotational information of a tyre attached to a driving shaft in the four-wheeled vehicle and a judged value calculated from the rotational information of the tyre attached to the four-wheeled vehicle; and cancelling a judgement of decrease in internal pressure when a difference between the judged value in the right



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turning region and the judged value in the left turning region is different from a difference between a reference judged value in the right turning region and a reference judged value in the left turning region which are obtained at a time of initialising run,

**[0009]** Hereinbelow, there is explained an apparatus and method for alarming decrease in tyre air-pressure of the present invention with reference to the accompanying drawings, in which

Figure 1 is a block diagram showing one embodiment of an apparatus for alarming decrease in tyre air-pressure of the present invention;
Figure 2 is a block diagram showing an electric arrangement of an apparatus for alarming decrease in tyre air-pressure shown in Figure 1;
Figure 3 is a view showing a relation between a judged value when a limited slip differential torque of a limited slip differential device (LSD) changes and a reference judged value;
Figure 4 is a view showing a relation between a judged value when internal pressure decreases and a reference judged value;
Figure 5 is one embodiment of a flow chart in accordance with the present invention;
Figure 6 is a view showing a relation between a DEL value and a reciprocal number of a turning radius calculated from a difference between right and left driving wheels when the limited slip differential torque is normal;
Figure 7 is a view showing a relation between a DEL value and a reciprocal number of a turning radius calculated from a difference between right and left driving wheels when the limited slip differential torque is reduced;
Figure 8 is a schematic view showing a relation between a DEL value and a reciprocal number of a turning radius calculated from a difference between right and left driving wheels, in accordance with the conventional art; and
Figure 9 is a schematic view showing change in DEL value at a time when the limited slip differential torque is increased or decreased.

**[0010]** As shown in Figure 1, an apparatus for alarming decrease in tyre air-pressure is so designed as to detect whether or not pneumatic pressures of four tyres FL, FR, RL and RR on a four-wheeled vehicle are decreased, and is provided with the usual wheel speed sensors 1 respectively provided in connection with the tyres FL, FR, RL and RR. Each wheel speed sensor 1 detects rotational information, for example, number of revolutions, rotational speed, angular velocity or the like. Further, an output of the wheel speed sensor 1 is applied to a control unit 2. To the control unit 2, a display device 3 for informing of the tyre FL, FR, RL and RR having a decreased pneumatic pressure, the display device 3 being constituted by a liquid crystal display element, a plasma display element, a CRT or the like, and an initialising switch 4 capable of being operated by a driver or the like are connected. Further, a limited slip differential device 7 is mounted on a differential gear 6 of a driving shaft 5. In this case, reference numeral 8 denotes a following shaft.

**[0011]** The control unit 2 includes, as shown in Figure 2, an I/O interface 2a required for giving and taking a signal with respect to an external device, a CPU 2b functioning as a centre of a calculating process, a ROM 2c storing a control operation program of the CPU 2b and a RAM 2d in which data is temporarily written or the written data is read at a time when the CPU 2b executes the control operation.

**[0012]** In the present invention, there is provided rotational information detecting means, memory means, calculation processing means, first judging means and second judging means.

**[0013]** The memory means stores the rotational information of each of the tyres detected by the rotational information detecting means, and the calculation processing means respectively calculates a reciprocal number of a turning radius from the rotational information of the tyre attached to the driving shaft among the respective tyre rotational information and calculates a judged value from the rotational information of the respective tyres. Then, the first judging means compares the judged value with the reference value at every region of the turning radius so as to judge decrease in internal pressure, on the basis of a relation between the reciprocal number of the turning radius and the judged value.

**[0014]** However, in the case where the limited slip differential torque of the LSD mounted on the vehicle changes with the passage of time, there is a risk that an erroneous alarm is issued even when the pneumatic pressure of the tyre is normal. Therefore, in accordance with the present invention, the apparatus is characterised that it includes second judging means for cancelling the judgement of decrease in internal pressure when absolute values of the respective judged values are substantially equal to each other between a right turning region and a left turning region of a vehicle running, thereby preventing the erroneous alarm from being issued.

**[0015]** In the present embodiment, the wheel speed sensor 1 corresponds to the rotational information detecting means, and the control unit 2 corresponds to the memory means, the calculation processing means, the first judging means and the second judging means.

**[0016]** Next, a description will be given of the calculation processing means, and the first and second judging means in accordance with the present invention, with respect to the case where a judged value (DEL value) is set to a ratio between a result obtained by subtracting a sum of signals from another pair of tyre wheels on a diagonal line from a sum of signals from a pair of tyre wheels on the diagonal line, and an average value of two sums.

**[0017]** Firstly, since the right and left driving wheels

rotate at the same speed until the turn is performed so that the torque over a determined limited slip differential torque is generated, the DEL value calculated by the following formula (1) is in proportion to a difference between the right and left following wheels during the period.

$$DEL = \frac{\frac{V_{(1)} + V_{(4)}}{2} - \frac{V_{(2)} + V_{(3)}}{2}}{\frac{V_{(1)} + V_{(2)} + V_{(3)} + V_{(4)}}{4}} \times 100 \qquad (1)$$

**[0018]** In the formula (1), V(X) is a tyre rotational speed (m/sec) and x is a tyre in which 1 is a front left tyre, 2 is a front right tyre, 3 is a rear left tyre and 4 is a rear right tyre.

**[0019]** That is, since the limited slip differential torque is dependent upon the turning radius as far as the vehicle does not run on a specific road surface, there has been known that, in the case where a reciprocal number $1/R_0$ of a turning radius $R_0$ is calculated from the difference between the right and left following wheels in accordance with the following formula (2) and the DEL value is employed for the judging value of pressure decrease, the DEL value becomes the difference itself between the right and left following wheels during the period that the differential operation is limited, and the DEL value becomes substantially fixed when the limitation is released.

$$\frac{1}{R_0} = \frac{1}{T_W} \times \frac{V(1) - V(2)}{V_{AVE}} \qquad (2)$$

**[0020]** In this formula (2), $T_W$ is a tread width and $V_{AVE}$ is an average value of the right and left tyres.

**[0021]** In this case, since DEL value is severely changed by the speed of the vehicle, the driving force, the lateral acceleration (lateral G) or the like, it is preferable to reduce a dispersion of the DEL value so as to improve accuracy by previously searching the influence in accordance with the vehicle then tuning so as to a apply correction, for example, with respect to a load movement at a time of turning, a change in the DEL value due to the driving force, or a sensitivity correction of the DEL value due to vehicle speed.

**[0022]** In the relation between the reciprocal number $1/R_0$ of the turning radius of the following wheel and the DEL value mentioned above, when the pressure of the driving wheel is decreased, a centre turning radius to be differential limited is shifter, and when the pressure of the following wheel is decreased, the calculation of the turning radius itself is shifted, so that the DEL value moves in parallel in a vertical direction along a line (a diagonal line) of the difference between the right and left following wheels. Accordingly, it is necessary to judge the pressure decrease by comparing a horizontal portion of the normal pneumatic pressure condition with a horizontal portion of the decreased pressure condition. Thus, it is necessary to identify from where the horizontal portion starts in both conditions. However, since the horizontal portion is changed in accordance with the tyre or size of a tyre, and its properties such as rigidity, a pressure decrease amount of the tyre or the like, it is very hard to define the horizontal portion (region).

**[0023]** Then, in the same manner as that of the conventional art, the present invention performs the first judging step by using experimental results obtained by running the vehicle having the LSD thereon to which the tyre (tyre size 225/45R17) having a normal pneumatic pressure (220 Kpa) is attached, on a public road in Germany including Auto-bahn, and running the vehicle in which the pneumatic pressures of four tyres attached to the LSD mounting vehicle are respectively and independently 40% decreased, in the same manner as that of the tyre having the normal pneumatic pressure. That is, the reciprocal number 1/R of the turning radius R calculated from the driving wheels and the DEL value are respectively set to the horizontal axis and the vertical axis, the relation between the reciprocal number 1/R of the turning radius R and the DEL value is searched, and thereafter, the value 1/R is separated into the following three regions, then, the data is simply averaged.

Right Turn: $1/R<-0.02$

Straight Run: $-0.002 \leq 1/R \leq 0.002$

Left Turn: $1/R>0.002$

**[0024]** Accordingly, since the horizontal portion can be easily determined, the comparison with the reference value (in this case, the average of the judged values near the straight run, at the left turn and at the right turn is calculated in the initialising run with the general internal pressure and this average is previously stored as the reference value at a time of initialising) at the normal pneumatic pressure, and the decrease in internal pressure is judged by comparing the DEL value with the reference value at every region of the turning radius 1/R. When the dispersion of the data in the straight portion is much, the pressure decrease judgement can be performed by increasing a threshold for pressure decrease judgement.

**[0025]** Further, in accordance with the present invention, in the case where it is judged by the judging means that the pneumatic pressure is decreased, the difference R between the judged value in the right turning region and the judged value in the left turning region is compared with the difference (reference difference) $R_0$ between the reference judged value in the right turning region and the reference judged value in the left turning region which were previously obtained during an initialising run. When the values R and $R_0$ are substantially equal to each other, for example, when the value R is



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within a range $R_0 \pm 0.1$, the pressure of the tyre is decreased. However, when the value R is smaller than the value $R_0$ such as a value R1 shown in Figure 3, or the value R is largely different from the value $R_0$ such as a value R2, for example, the difference between the judged value in the right turning region and the judged value in the left turning region is different from the reference difference by not less than 0.2, it is judged that the limited slip differential torque of the LSD is changed, so as to cancel the judgement of the decrease in internal pressure. Accordingly, it is possible to prevent an erroneous alarm from being issued so as to accurately judge the decrease in pneumatic pressure.

**[0026]** Here, in the case where the limited slip differential torque is not changed and only the pneumatic pressure of a tyre is chanted, a difference A1 between the judged value in the right turning region and the judged value in the left turning region becomes always constant even when the judged value is changed as shown in Figure 4, so that the pressure decrease judgement is kept in this case.

**[0027]** In this case, it is known that the DEL value near the straight line in a winter tyre becomes larger than the judged value (DEL value) near the straight line in a summer tyre, and that the judged values in the left turning region and the right turning region are different from each other.

**[0028]** Therefore, in accordance with the present invention, since it is possible to determine that the winter tyre is employed when the absolute values of the reference value at a time of turning right and left are both equal to or more than 0.1, and that the summer tyre is employed in the other cases, the decrease in internal pressure is judged by comparing the judged value with the reference value at every region of the turning radius on the basis of the relation between the reciprocal number of the turning radius and the judged value, after identifying whether the tyre attached to the driving shaft is the summer tyre or the winter tyre. Next, when the difference between the judged value in the right turning region and the judged value in the left turning region is different from the reference difference, the second judging means cancel the judgement of the decrease in internal pressure and prevents the erroneous alarm from being issued. In this case, in order to identify whether the tyre is the summer tyre or the winter tyre, it is preferable to provided with the identifying means determining on the basis of the relation between the reciprocal number of the turning radius and the judged value.

**[0029]** Next, a description will be given of the present invention on the basis of an example, however, the present invention is not limited only to the Example.

EXAMPLE

**[0030]** At first, a tyre having a normal pneumatic pressure (220 Kpa) was fitted to a vehicle having a limited slip differential device, and the vehicle was run on a public road including a highway. A graph was obtained by respectively setting a reciprocal number 1/R of a turning radius calculated from the driving wheels and a DEL value on the basis of data at this time to a horizontal axis and a vertical axis, as shown in Figure 6. The limited slip differential torque at this time was 105 Nm. It is known from Figure 6 that an average value of the DEL value at a time of the normal pneumatic pressure is about 0.4 at a time of right turning, about 0.1 at a time of straight running, and a bout -.02 at a time of left turning (step S1). In this case, these values respectively become reference values in the respective cases.

**[0031]** Next, the running test in the same manner as that mentioned above was applied to the vehicle having the normal pneumatic pressure tyre under a state that the limited slip differential torque was reduced to 6 Nm, and the data was collected. Further, as shown in Figure 7, a graph between the reciprocal number 1/R of the turning radius and the DEL value is prepared (step S1). In this case, although the pneumatic pressure of the tyre was normal, the DEL value in the right turning region was about 0.1 and was largely different from the reference value about 0.4 (step S2), so that it was judged to be a pressure decrease (step S3). However, when calculating a difference between the DEL value in the right turning region and the DEL value in the left turning region, the value becomes about 0.1 and is very small in comparison with the difference of about 0.6 between the reference value in the right turning region and the reference value in the left turning region (steps S4 and S5), so that the pressure decrease judgement was cancelled by judging that the limited slip differential torque was reduced (steps S6 and S7). In this case, when the difference between the DEL value in the right turning region and the DEL value in the left turning region with the difference between the reference value in the right turning region and the reference value in the left turning region was very large, a pressure decrease alarm was issued (step S9).

**[0032]** Further, in the case where the state mentioned above was generated, it was possible to correct the reference value to a proper value by outputting an alarm (command) for promoting a re-initialisation (step S8).

**[0033]** As mentioned above, according to the present invention, it is possible to properly judge decrease in internal pressure of a tyre on a vehicle having a LSD or the like thereon, thereby securely preventing an erroneous alarm from being issued.

## Claims

1. An apparatus for alarming decrease in tyre air-pressure which alarms decrease of internal pressure of a tyre on the basis of a rotational information obtained by tyres attached to a four-wheeled vehicle, **characterised by** rotational information detecting means for detecting rotational information of each



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of the tyres; memory means for storing the rotational information of each of the tyres; calculation processing means for calculating a reciprocal number of a turning radius from the rotational information of the tyres attached to a driving shaft among the rotational information of the respective tyres and calculating a judged value from the rotational information of the respective tyres; first judging means for comparing the judged value with a reference value at every region of the turning radius on the basis of a relation between the reciprocal number of the turning radius and the judge value so as to judge decrease in internal pressure; and second judging means for cancelling a judgement of decrease of internal pressure when a difference between the judged value in the right turning region and the judged value in the left turning region is different from a difference between a reference judged value in the right turning region and a reference judged value in the left turning region which are obtained at a time of initialising run.

2. A method for alarming decrease in tyre air-pressure which alarms decrease of internal pressure of a tyre on the basis of rotational information obtained by tyres on a four-wheeled vehicle, **characterised by** the steps of comparing a judged value with a reference value at every region of a turning radius so as to judge decrease in internal pressure on the basis of a relation between a reciprocal number of the turning radius calculated from the rotational information of a tyre attached to a driving shaft in the four-wheeled vehicle and a judged value calculated from the rotational information of the tyres attached to the four-wheeled vehicle; and cancelling a judgement of decrease in internal pressure when a difference between the judged value in the right turning region and the judged value in the left turning region is different from a difference between a reference judged value in the right turning region and a reference judged value in the left turning region which are obtained at a time of initialising run.



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FIG. 1

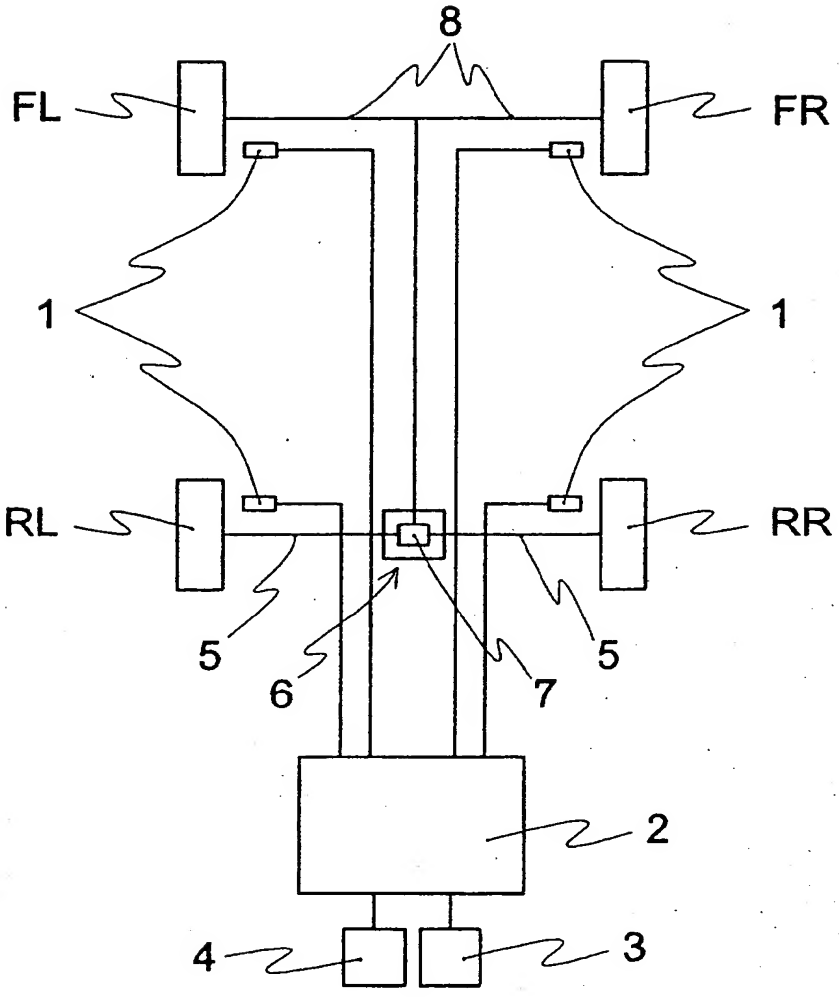

FIG. 2

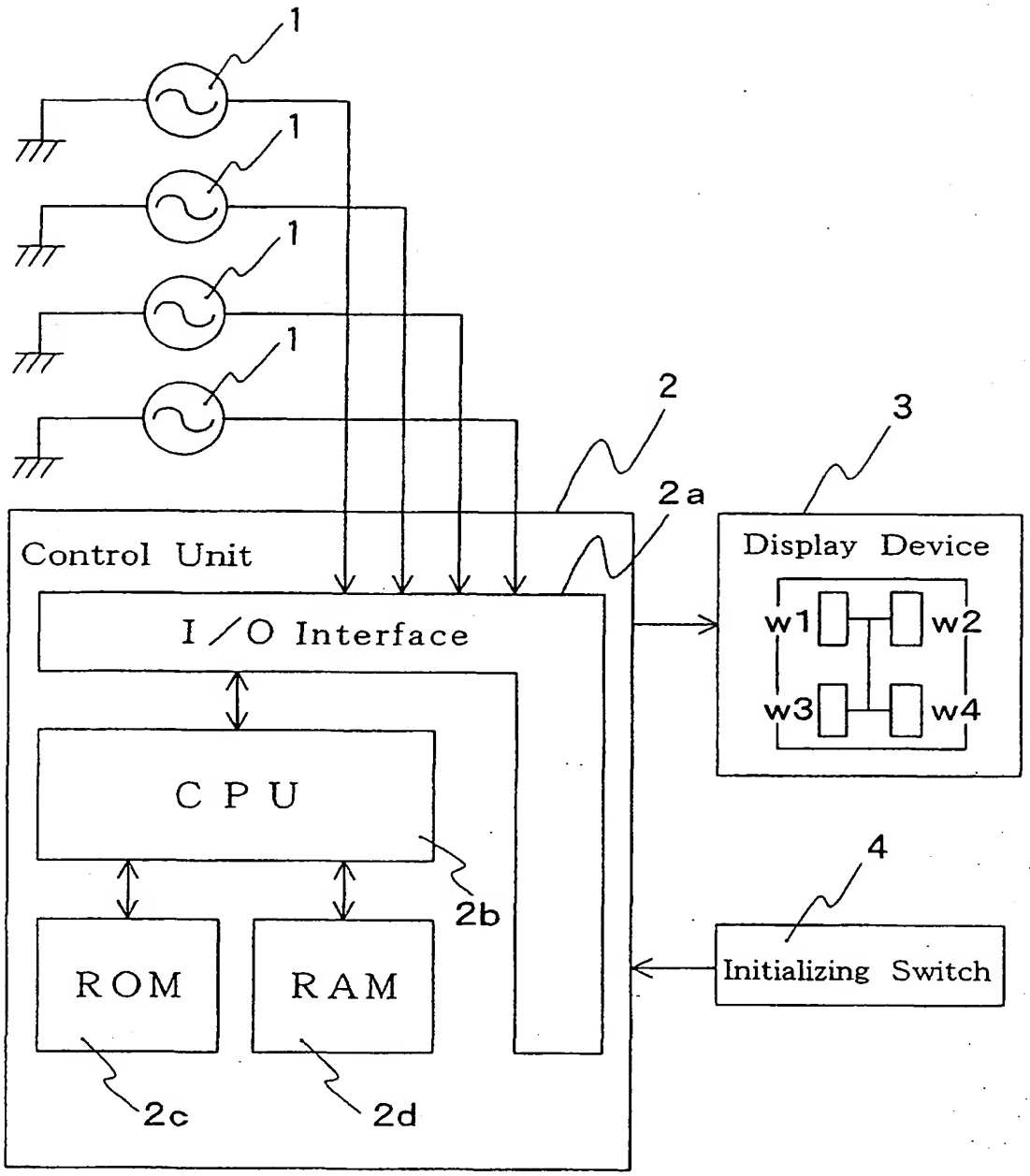




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FIG. 3

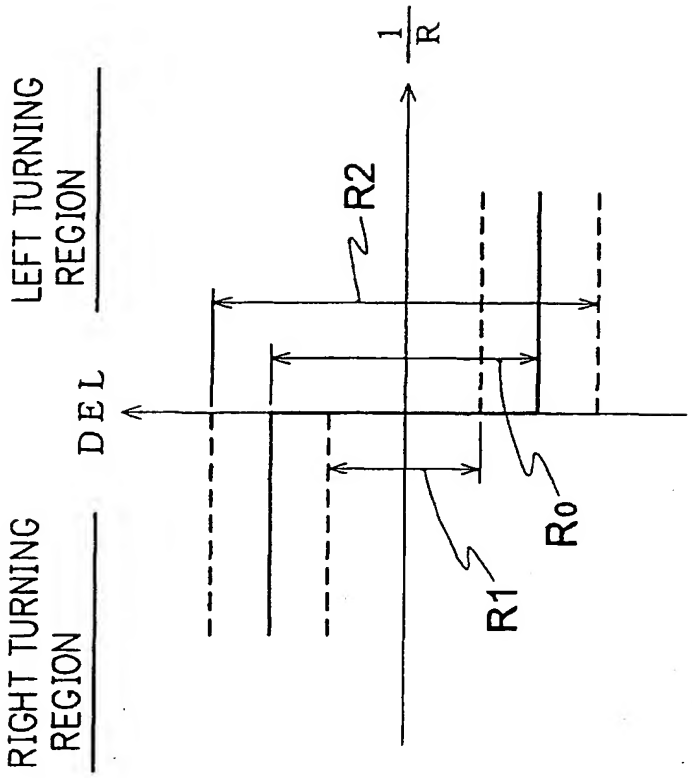

FIG. 4

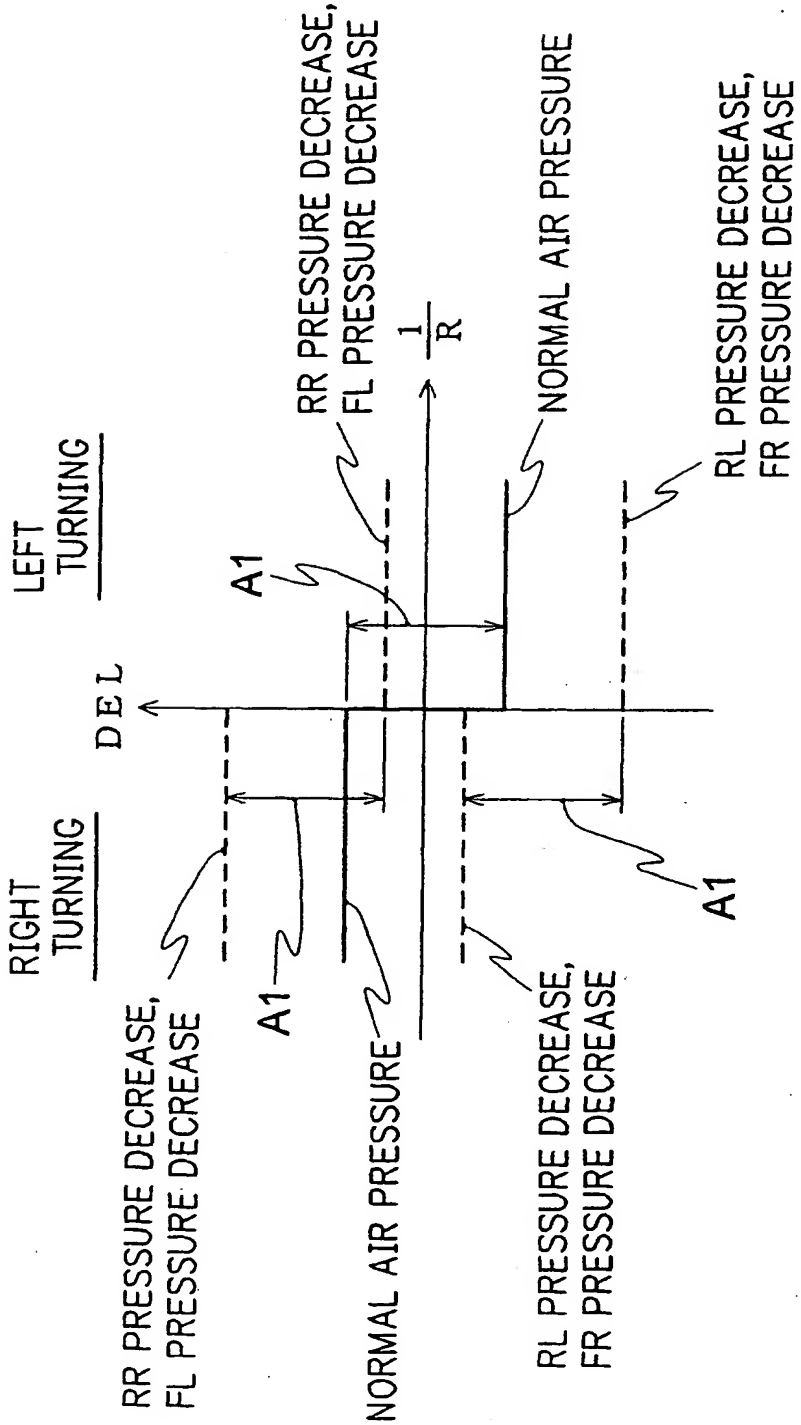




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FIG. 5

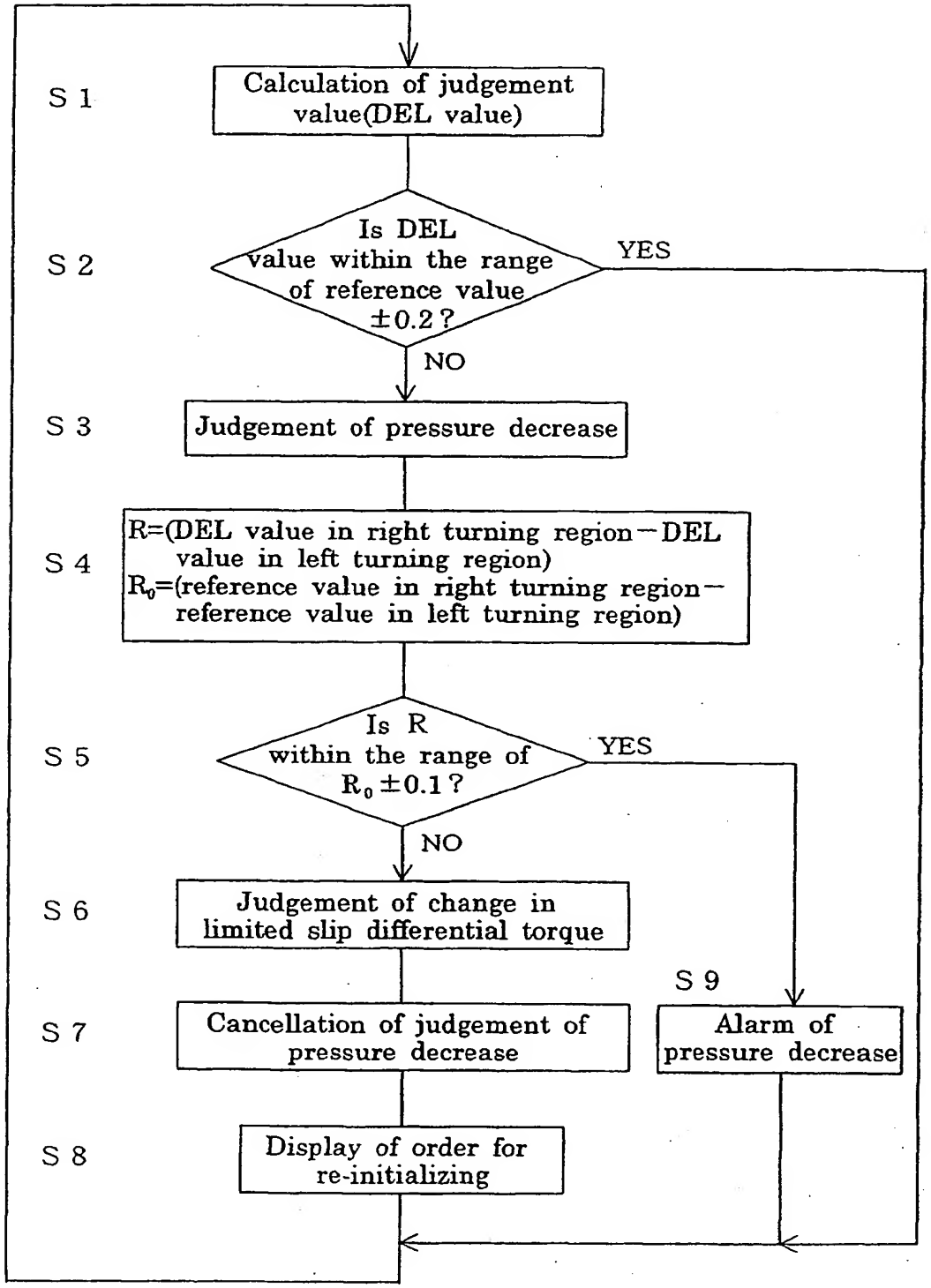
S 1
Calculation of judgement value(DEL value)
S 2
Is DEL value within the range of reference value ±0.2?
YES
NO
S 3
Judgement of pressure decrease
S 4
R=(DEL value in right turning region−DEL value in left turning region)
R0=(reference value in right turning region−reference value in left turning region)
S 5
Is R within the range of R0±0.1?
YES
NO
S 6
Judgement of change in limited slip differential torque
S 7
Cancellation of judgement of pressure decrease
S 8
Display of order for re-initializing
S 9
Alarm of pressure decrease

FIG. 6

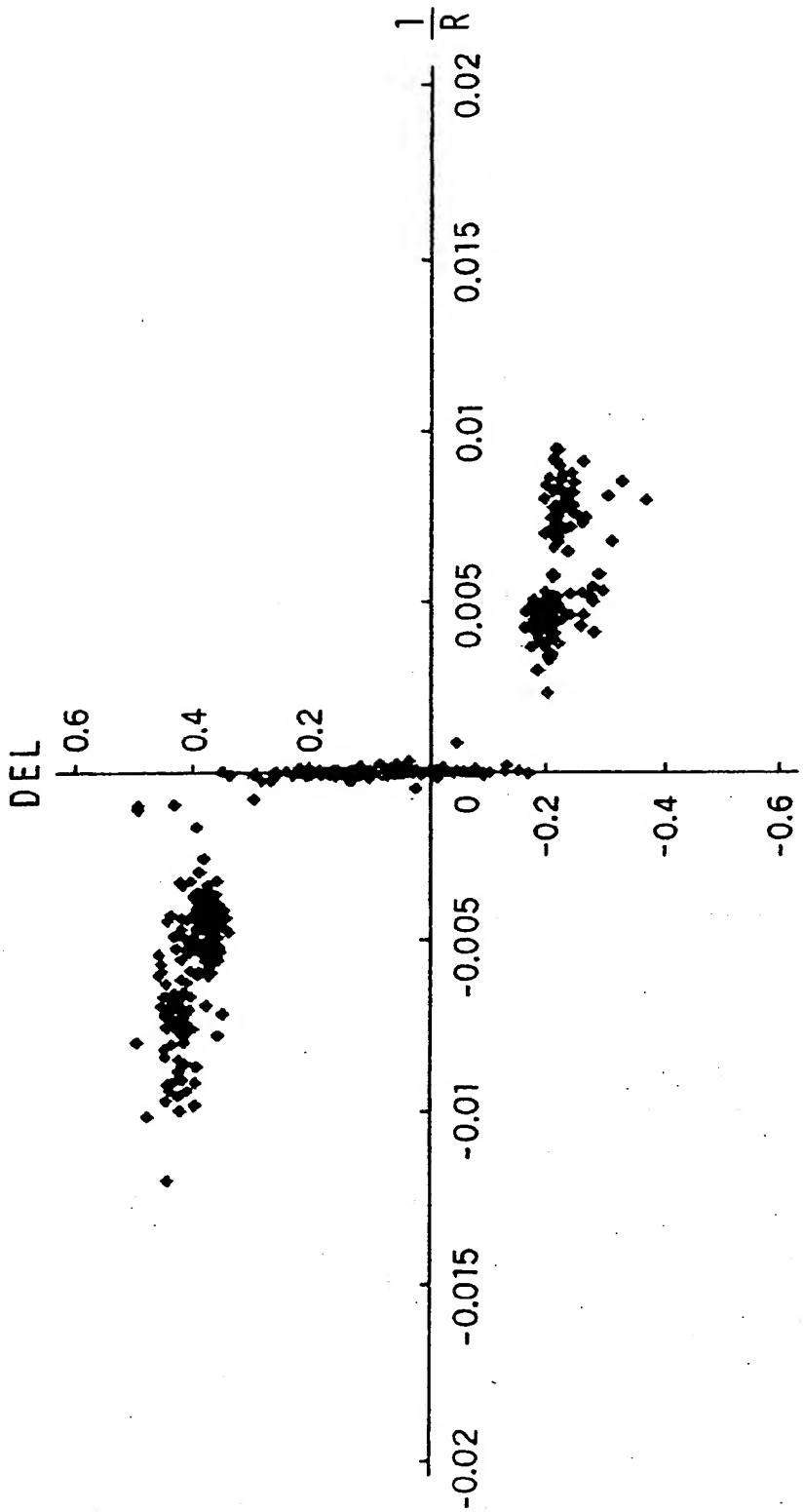




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FIG. 7

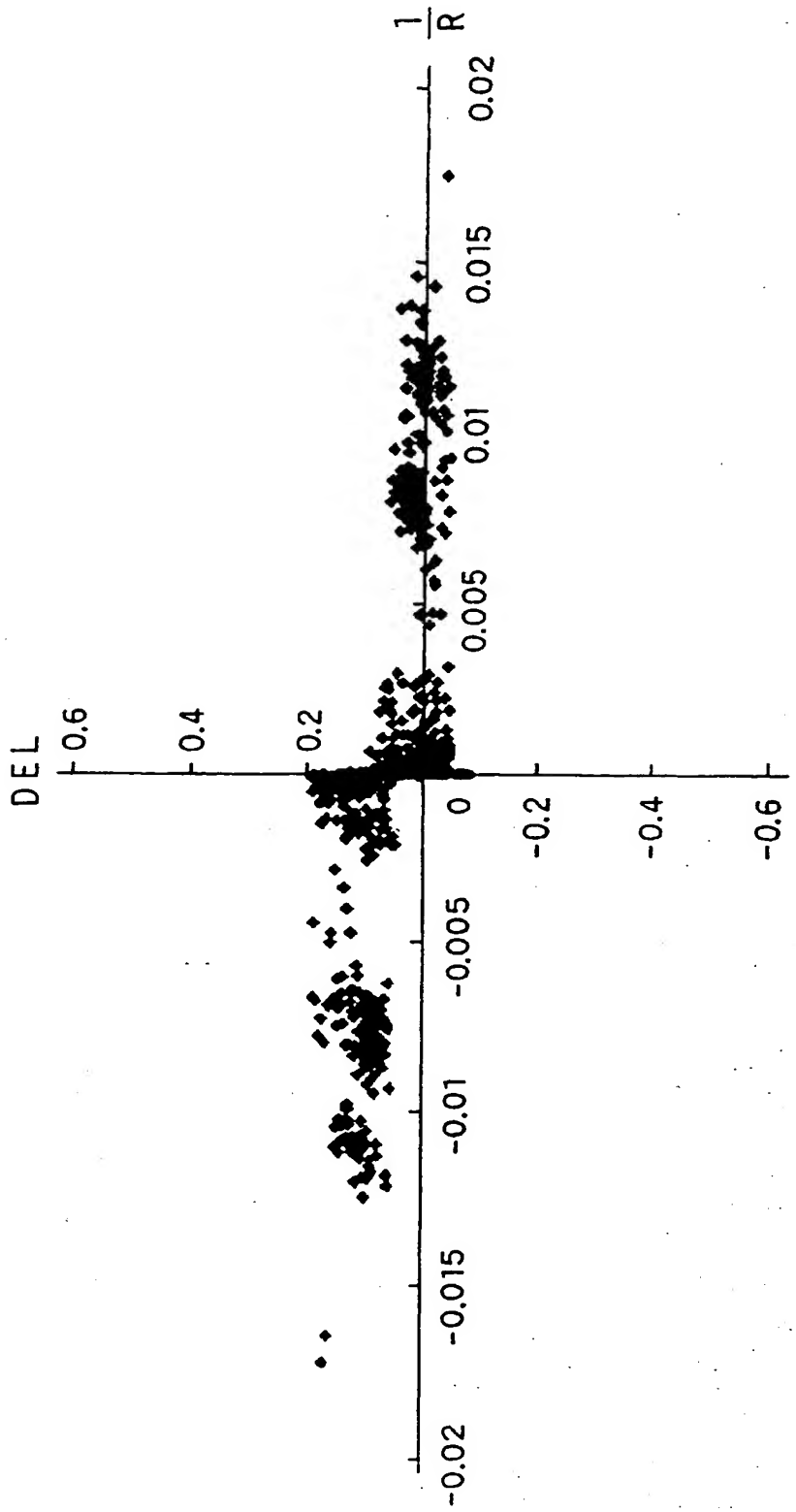




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FIG. 8

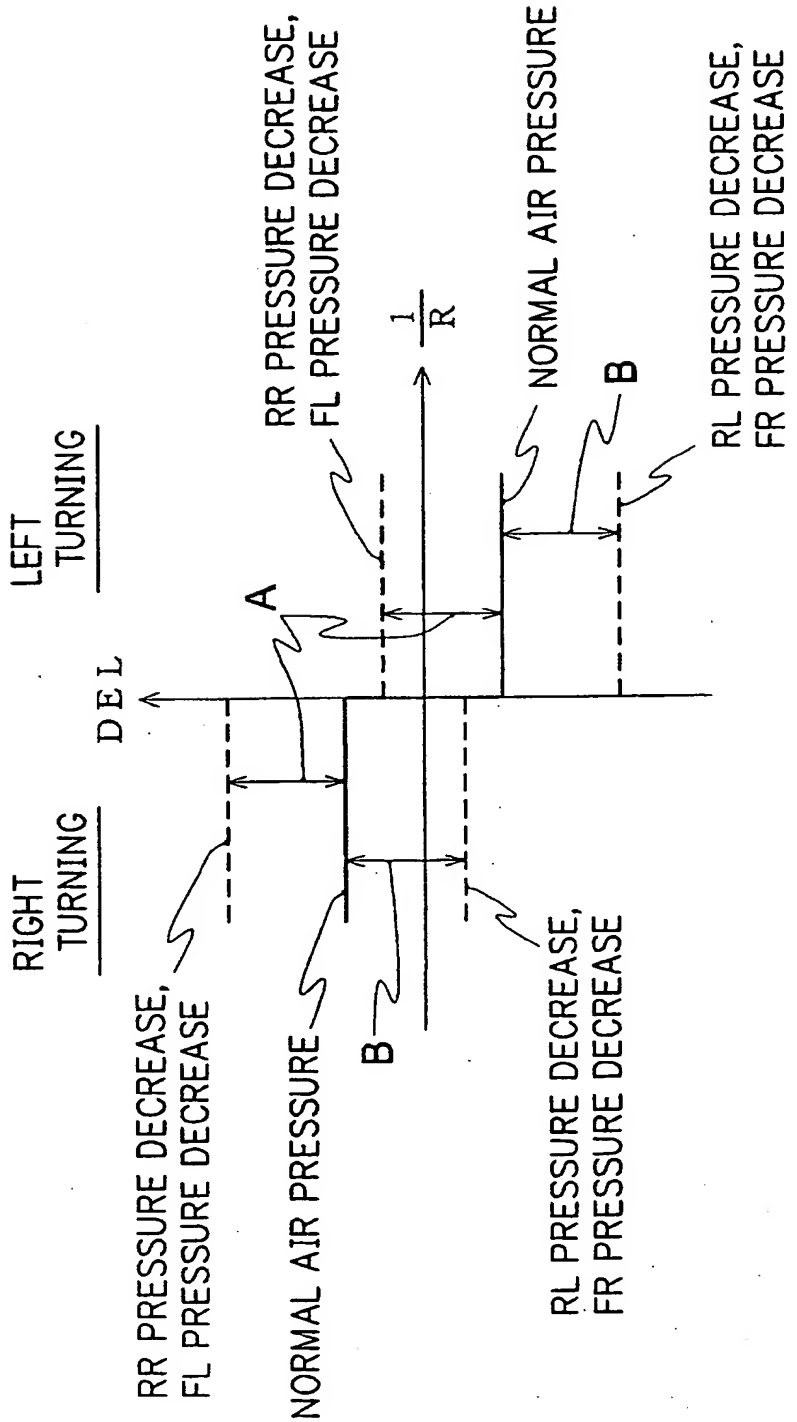




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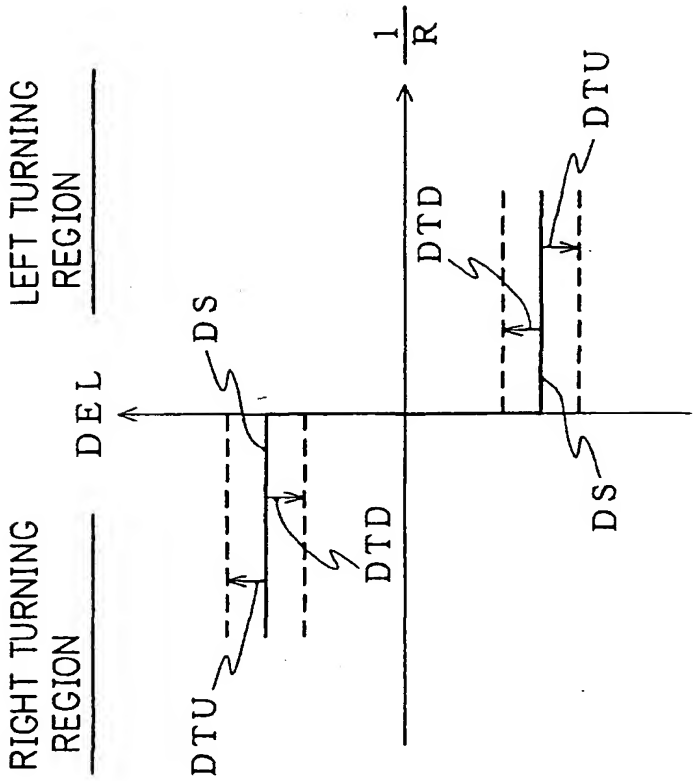
FIG. 9


LEFT TURNING REGION
RIGHT TURNING REGION
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DTU
DTD
DS

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European Patent Office
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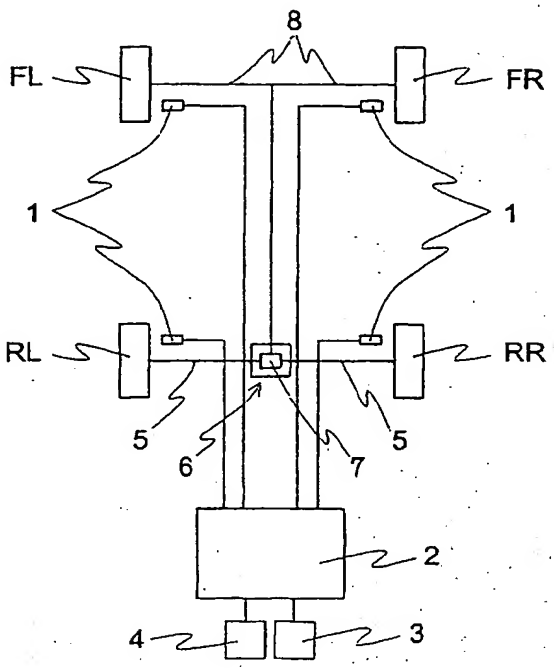
## (54) Apparatus and method for alarming decrease in tyre air pressure

(57) An apparatus for alarming decrease in tyre air-pressure on the basis of a rotational information obtained by tyres attached to a four-wheeled vehicle, comprising rotational information detecting means; memory means for storing the rotational information; calculation processing means for calculating a reciprocal number of a turning radius and calculating a judged value, first judging means for comparing the judged value with a reference value at every region of the turning radius; and second judging means for cancelling a judgement of decrease of internal pressure when a difference between the judged values in the right and left turning regions is different from a difference between reference judged values in the right and left turning regions which are obtained at a time of initialising run.

FIG. 1

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European Patent Office

# EUROPEAN SEARCH REPORT

Application Number
EP 01 30 3350

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
|---|---|---|---|
| A | EP 0 897 816 A (SUMITOMO RUBBER IND ;SUMITOMO ELECTRIC INDUSTRIES (JP)) 24 February 1999 (1999-02-24) * the whole document * ----- | 1,2 | B60C23/06 |

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

B60C

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| MUNICH | 13 May 2003 | Vessière, P |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 01 30 3350

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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13-05-2003

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(19) Europäisches Patentamt
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(11) EP 1 145 875 A8

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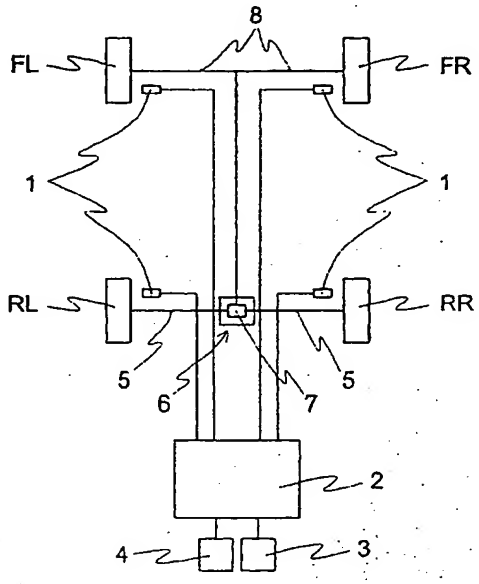


EP 1 145 875 A8